NORTH AMERICAN VERTICAL DATUM (NAVD) UPDATE

David B. Zllkosk! and Gary M. Young
Vertical Network Branch
National Geodetic Survey
Charting and Geodetic Services
National Ocean Service, NOAA
Rockville, Maryland 20852

BIOGRAPHICAL SKETCHES

David B. Zllkoski received a B.S. degree in forestry from the College of Environmental Science and Forestry* Syracuse? New York» in 1974. and a M.S. degree in geodetic science from the Ohio State University In 1979. He has been employed by the National Geodetic Survey (NGS) since 1974. From 1974 to 1981, as a member of the Horizontal Network Branch, he participated 1n the North American Datum readjustment project. In 1981, he transferred to the Vertical Network Branch, and currently serves as Chief, Vertical Analysis Section. Mr. Zilkoski Isa member of ACSM, and Is an Instructor for the NGS Vertical Control Workshop and ACSM-NGS Surveying Instrumentation and Coordinate Computation Workshops. He Is also a member of AGU and IAG Special Study Group 4.96, "Models for Time-Dependent Geodetic Positioning."

Gary M. Young 1s Acting Chief, Vertical Network Branch, National Geodetic Survey. He received a B.S. degree in mathematics from Virginia Polytechnic Institute and State University in 1965. In 1970, he received a M.S. degree In engineering, with a specialization In geodesy, from Purdue University. Since 1965, he has been with the National Ocean Service's National Geodetic Survey (formerly the U.S. Coast and Geodetic Survey). He first served as a geodesist and later as New Datum Coordinator of the North American Datum readjustment project in NGS' Horizontal Network Branch. Beginning 1n 1976, he became Assistant Chief of the Vertical Network Branch. He is a member of ACSM and AGU.

ABSTRACT

This report provides a brief history of the vertical control portion of the National Geodetic Reference System (NGRS) and presents an update of the progress by the National Geodetic Survey on the North American Vertical Datum of 1988 (NAVD 88) readjustment project. This project, scheduled for completion in 1988, has dominated Vertical Network Branch activities since the project received approval and funding, beginning 1n fiscal year (FY) 1978. The total project Includes several production and research efforts. The most Important of these are described In this report.

BACKGROUND

The first leveling route In the United States that can be considered to be of geodetic quality was performed 1n 1856-57 under the direction of G. B. Vose. U.S. Coast Survey (now called the National Ocean Service). The leveling survey was required to support currents and tides studies In the New York Bay and Hudson River areas. The first leveling line that was officially designated "geodesic leveling" by the Coast and Geodetic Survey followed an arc of triangulatlon along the 39th parallel. This leveling survey began In 1887. at bench mark A 1n Hagerstown» Maryland.

By 1900. the vertical control network had grown to 21,095 km of leveling that could be considered "geodetic". These data Included work performed by the Coast and Geodetic Survey, various components of the Corps of Engineers, the U.S. Geological Survey, and the Pennsylvania Railroad. A "mean sea level" reference surface was determined 1n 1900 by holding elevations fixed at five tide stations.
Two other tide stations participated indirectly. Subsequent readjustments of the leveling network were performed by the Coast and Geodetic Survey In 1903 (a total of 31,789 km of leveling; eight tide stations were used); 1907 (a total of 38,359 km of leveling; eight tide stations were used); and 1912 (46,462 km of leveling, nine tide stations were used) (Berry, 1976).

The next general adjustment of the vertical control network did not occur until 1929. By then the International nature of geodetic networks was well understood and Canada provided its first-order vertical network which was combined with the U.S. net. The U.S. network had grown to 75,159 km of leveling. Canada provided an additional 31,565 km. The two networks were connected at 24 vertical control points (bench marks) that extended from Maine/New Brunswick to Washington/British Columbia. Mean sea level was held fixed at 21 tide stations In the United States and five in Canada. Although Canada did.not adopt the "Sea Level Datum of 1929" determined by the United States, Canadian - U.S. cooperation in the general readjustment strengthened both networks.

INACCURACIES INTRODUCED IN THE 1929 DATUM RESULTS

At the time of the 1929 General Adjustment It was known that local mean sea level at the various tide stations held fixed (at 0.0 elevation) during the adjustment could not. In reality, be considered to be on the same equipotential surface. This 1s due to the so-called sea-surface topography effect, currents, water temperature and salinity, barometric pressure, etc. It was thought at that time, however, that the errors Introduced by this approach were not significant, being of the same order of magnitude of terrestrial leveling observational errors. We now know that significant errors were introduced into the 1929 General Adjustment by considering each of the tide stations to be on the same equipotential surface. The error 1s estimated to be as much as 0.7 m from coast to coast.

Recognition of this distortion, and confusion concerning the proper definition of local mean sea level resulted, in 1976, in a change in designation of the official height system from "Sea Level Datum of 1929" to "National Geodetic Vertical Datum of 1929" (NGVD

29) (Federal Register, 1976). The change was in name only; the same geodetic height system continues from 1929 to the present.

There are several other distortions In the present NGVD 29 system.
Some will be discussed later In this report.

READJUSTMENT OF THE NORTH AMERICAN VERTICAL DATUM OF 1988

Approximately 625,000 km of leveling have been added to NGRS since the 1929 adjustment. In the Intervening years, numerous discussions were held to determine the proper time for the Inevitable new General Adjustment. In the early 1970's, NGS conducted an extensive Inventory of the vertical control network. The inventory Identified thousands of bench marks that had been destroyed, due primarily to post-World War II highway construction, as well as other causes. Many existing bench marks had become unusable due to crystal motion associated with earthquake activity, post-glacial rebound (uplift), and subsidence caused by the withdrawal of underground liquids. Other problems were caused by forcing the 625,000 km of leveling to fit previously determined NAVD 29 height values. These distortions, amounting to as much as 9 m. are Itemized In Table I:

Source of Distortion	Approximate Amount (Meters)
Patching 625K Km to Old 75K Km Net	0.3
Constraining Tide Gage Heights In NGVD 29	0.7
Ignoring True Gravity in NGVD 29	1.5
Refraction Errors	2.0
Post-Glacial Uplift; Minnesota, Wisconsin, Etc.	0.6
Subsidence From Withdrawal of Fluids	9.0
Crustal Motions From Earthquakes	2.0
Bench Mark Frost Heave	0.5

Table 1. Distortions In Present NGVD 29 System.

In 1973, the "Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying," Office of Management and Budget (1973), stated. In part:

"The fundamental geodetic networks have become incomplete through obsolescence and need new surveys and a National Adjustment to meet modern demands... based on our requirements study, we conclude the vertical control program is falling short of meeting national needs, and, therefore, must be expanded... We recommend doubling the National vertical control program."

A position paper, prepared by the National Geodetic Survey (NGS). Soon followed, specifying the tasks and amount of effort required to modernize the vertical control network (National Ocean Survey. 1976). In 1978, the National Research Council's National Academy of Science's Committee on Geodesy (1978) stated In "Geodesy: Trends and Prospects";

"We recommend that the computations and additional observations for the new adjustments of the North American Horizontal and Vertical Control Networks by the National Geodetic Survey be given the support necessary to bring about their completion 1n an orderly way."

"We endorse for scientific, as well as practical reasons, the adjustment of the North American -vertical control network..."

"The committee endorses the efforts of the National Geodetic Survey to systematize, update and adjust the national horizontal and vertical control networks... these data constitute a valuable framework for decades to come."

NGS prepared a budgetary initiative for fiscal year 1977 to finance this project. The Initiative was not approved. A revised plan was later approved and the General Adjustment program formally began at the beginning of FY 1978. The program called for the completion of several tasks. These tasks win be discussed In more detail later In this report.

INTERNATIONAL COOPERATION

Early In 1982, Canada and the United States reached agreement on many of their cooperative efforts for the new adjustment and signed a formal Memorandum of Understanding concerning the NAVD 88 readjustment project. The agreement, which was signed by officials of the Canadian Surveys and Mapping Branch and the U.S. National Oceanic and Atmospheric Administration, stated:

"Adoption of a Common North American Vertical Datum (NAVD 88)

Purpose and Participants

The National Oceanic and Atmospheric Administration, an agency of the Government of the United States of America, and the Surveys and Mapping Branch, an agency of the Government of Canada (hereinafter the "parties"), both having responsibilities 1n the geodetic field and both desirous of ensuring the adoption and Implementation of a common geodetic vertical datum by the two agencies, agree as follows:

1. The parties agree to cooperate In the 1988 North American Vertical Datum (NAVD 88) project and work toward Its completion by the end of 1988.

2. The parties agree to coordinate and share research and development related to the project.

3. The same reference surface, as near the geoid as practicable, wi11 be used by both parties as the common datum.

4. The practical or technical realization of a common NAVD win be defined by both parties and wm be determined and adopted in a mutually agreeable manner.

5. Both parties agree to adopt the same system of heights and to use compatible mathematical models of corrections to account for systematic errors In the observation of height differences and compatible procedures to incorporate tidal, gravitational, and atmospheric loading effects.

6. For the common adjustment* both parties agree to provide potential differences, based on observed gravity and elevation differences, corrected for systematic error.

7. The parties will agree on the "border Junction points" to be used In the adjustment and will confer on the other details associated with the adjustment. For this purpose, their representatives shall meet at least once each year until the completion of the project.

8. The parties agree to utilize NAVD 88 upon completion of the project or as soon as practical thereafter.

9. The rate at which new maps and charts will Incorporate NAVD 88 win vary between the parties and will be determined in each case by practical and economic considerations.

10. Costs Incurred under this agreement shall be borne by the party Incurring such costs.

11. It Is understood that the ability of the parties to Implement this agreement 1s subject to the availability of appropriated funds.

12. This agreement may be amended at any time by the mutual consent of the parties concerned.

13. This agreement will become effective upon the signature of both parties and win remain In effect until terminated by mutual agreement or upon 30 days written notice by either party to the other.

14. Nothing herein Is Intended to conflict with respective laws and regulations applicable to each of the parties. If the terms of this agreement are found Inconsistent with existing regulations or law applicable to each of the parties, then those portions of the agreement which are determined to be Inconsistent shall be Invalid, but the remaining terms and conditions of this agreement not affected by any Inconsistencies, shall remain In full force and effect."

Similar cooperation win lead to the Incorporation of leveling data from Mexico and the Central American countries, making the new vertical datum a truly international one. As reported in the Federal Register (1983), the designation of the new reference for the vertical control network will be the "North American Vertical Datum of 1988," which will also be referred to as "NAVD of 1988" and "NAVD 88." to acknowledge the International scope of the cooperation In the project, and the consistency of the results. The Improved geodetic heights are scheduled for distribution In 1989.

TASKS REQUIRED BY THE NAVD 88 READJUSTMENT PROJECT

Conversion of Data (Descriptive and Archival Observational Leveling Data) to Computer-Readable Form. The first major NAVD task to be completed was the conversion to computer-readable form of descriptive data (bench mark descriptions) from paper copy (primarily field records) under the direction of NGS,' National Geodetic Information Branch personnel. In early 1975. NGS applied for and received 1 year of funding under an amendment to the Publ1c Works and Economic Development Act of 1965. The legislation required the funds be spent In an area of high unemployment. Detroit, Michigan, was selected as the potential contract site and the Department of Commerce solicited bids on the project. By January 1976» the contract was awarded.

Preliminary NGS preparation Included finalizing formats, preparing conversion Instructions, and selecting an on-slte technical representative. Descriptions were organized Into areas based upon their geographic location within blocks of l-by-2 degrees of latitude and longitude. The descriptions were sequenced by line numbers In the order desired for publication, updated with recent recovery reports, edited for data omissions or obvious errors, and assigned unique Identifiers (designated archival cross reference numbers). This identifier was to serve as the link between bench mark data stored In various computer files.

Acceptable error rates were stipulated to be less than 0.3 percent per data set. All data were key-verified and copied to magnetic tape by contract personnel for shipment to

NGS. Agency personnel proofread a sample of submitted data sets. Software was developed to read each data set and check for format errors or data omissions. Despite lost data shipments, a parcel delivery service strike, and tornado damage to the contractor's plant, this contract was successfully completed in March 1977 with a minimum of data-set rejections.

Approximately 60 percent of the active descriptions contained in agency files were automated at a cost of $330,000. In October 1977, a similar contract was awarded to a Rockvme, Maryland, firm. Work proceeded smoothly, and by January 1980, the entire file had been automated. A total of 457,000 bench mark descriptions had been automated over the 4-year period at an approximate contract cost of $600.000.

Today all new bench mark descriptions and recovery notes are automated by NGS field personnel as standard operating procedure for new field projects. This Information 1s merged Into existing files with software programmed to adhere to specifications as stated In theFederal Geodetic Control Committee's publication "Input Formats and Specifications of the National Geodetic Survey Data Base, Volume II; Vertical Control Data," commonly referred to as the Blue Book. The descriptions reside on five off-line disk packs and can be retrieved by archival cross reference number, state, quadrangle, or county.

The second major task to be completed for the NAVD project was the conversion,of archival (historic) observational leveling data to computer-readable form (Tin, 1983). In 1975 NGS began retrieving all its original leveling records held in the National Archives and the Washington Federal Records Center. Because of the large volume of data (approximately 50,000 field books). It was necessary to acquire the data over a period of several years. The retrieval of data was accomplished on a state-by-state basis, following the manner In which the data were stored in the archives. Because this undertaking involved a large volume of data. It was decided that Instead of keying individual level ing-rod readings, as Is presently done with new NGS surveys, only the stadia Intervals, section elevation difference, date, time, "sun code," "wind code," temperature, and number of setups would be converted to computer-readable form.

This conversion was Initiated using personnel of the Vertical Projects Section, Vertical Network Branch (VNB). After a period of 1 year. It was decided that these personnel would not be able to convert the observations within the time frame set for the readjustment. Subsequently. In July 1976, a private contract was awarded to convert and validate the archival leveling data. In April 1978, this contract was replaced by one which was responsible for key punching only. (It was learned from the original contract that data validation was best accomplished by NGS.) Beginning with the second contractor, the VNB provided direct technical supervision of the conversion to computer-readable form, and was solely responsible for the validation and review processes. This proved to be very successful. In January 1982. the conversion of all NGS archival observational leveling data to computer-readable form was completed.

The data were processed through a series of computer programs which included "range" checks on Individual data fields to ensure the data were "reasonable." Verification of the leveling observations was accomplished by computer recomputation of the leveling lines. The resulting computations were compared against abstracts of the original field computations. Comparisons between Individual section lengths and between Individual section elevation differences were two of many checks the programs accomplished. The programs also indicated excessive corrections for instrument collimation. When a leveling line was double run, additional comparisons were made. The editing, validation, and review of all archival leveling data were completed in November 1982.

Geographic Positions for Bench Marks. In order to provide automated retrieval capability and apply position-dependent corrections to the observations, a geographic position (latitude, longitude) has been determined for each of the 515,000 bench marks. For those monuments not part of the horizontal control network, the effort Involved plotting bench marks on appropriate maps (using the descriptive data mentioned previously) and then determining a "scaled" position using digitizing equipment. This task, which began In 1975, and completed in May 1984, Involved a joint effort of personnel from the Vertical Network Branch, Operations Branch, National Geodetic Information Branch, and the Pacific Marine Center of NOS. Approximately 100,000 of these geographic positions were determined under contract to a private firm In Long Beach, California.

Releveling In Support of the NAVD 88. An Important feature of the NAVD 88 program Is the releveling of much of the first-order vertical control network In the United States. The dynamic nature of the vertical control network requires a framework of newly observed elevation differences In order to obtain realistic contemporary height values from the readjustment. To accomplish this, NGS has Identified 83,000 km of the network for releveling. Replacement of disturbed or destroyed monuments precedes the actual leveling. This effort also Includes the establishment of highly stable "deep-rod" bench marks, which will provide reference points for future "traditional" or "satellite" leveling systems. Field leveling 1s being accomplished to firstorder, class II specifications, using the "double-simultaneous" method. An Increase 1n leveling progress (while maintaining acceptable accuracy) has been accomplished by equipping NGS field leveling units with specially modified subcompact trucks for rodman as well as observers. This form of "motorized" leveling has Increased production by at least 20 percent as compared to former leveling procedures. Alternate approaches, including high-accuracy trigonometric leveling, are also being evaluated (Whalen, 1984a). To date, 56,000 km of leveling progress have been accomplished. Completion of field leveling Is scheduled for September 1987. Older data which are consistent with the newly observed data win be Included In the final framework for the readjustment.

Preparation of New Leveling. This activity, being performed in the Geodetic Leveling Section, VNB, processes both NGS and non-NGS new leveling projects. The proposed goal 1s to process 106,000 km of new leveling by September 1986. The tasks consist of validating data fields, applying appropriate corrections, and loading the data Into the Vertical Data Base (Balazs, 1984). As of December 1984, 79,000 km of leveling have been processed (75 percent complete).

REDUC4 Processing. This procedure consists of converting files from "Blue Book" format (Koepsell and Ward, 1984) to the vertical observation library file format, checking the fields for valid entries, calculating and applying corrections to leveling observations, and loading data Into the VNB Data Base. The National Geodetic Vertical Control Network consists of 16,000 leveling lines. The current goal is to process all data lines through the REDUC4 program by March 1985. As of December 1984, 15,666 leveling lines have been processed.

Block Validation. Block validation Is a process where all observed elevation differences In a predefined area are combined together and analyzed. There are many steps performed during block validation. During the analysis, a first-order primary network, consisting of the latest data, is selected, analyzed, and documented. Appropriate remaining leveling data are then Incorporated Into the first-order network. Leveling lines which do not fit (statistically) with the network will not be Included 1n the primary network and win be documented In the report. During the analysis, profiles, loop closures (primary and secondary), section misclosures, date of data, survey order and class, bench mark stability, previous adjustment reports, and past studies are all utilized to make decisions about the data.

As of December 1984, 129,000 bench marks have been processed. The current goal Is to process all bench marks by September 1987.

Magnetic Error Modeling. Approximately 50,000 km of NGS leveling lines were observed with compensator-type leveling Instruments. It was recently determined that the "horizontal" line of sight of compensator (automatic) leveling Instruments was Influenced by magnetic fields (Rumpf and Meurlsh, 1981). Professor Rumpf, Invited to join.forces with NGS, and Charles Whalen. then Chief of VN8, now retired, designed a magnetic calibration facility at NGS' Instrumentation and Equipment Section located In Frederlcksburg, Virginia (Whalen, 1984b). All NGS compensator leveling Instruments have been calibrated at this facility. The Influence of d.c.-lnduced magnetic fields (e.g., the Earth's magnetic field) on NGS compensator leveling Instruments Is now well understood. The task remaining to be completed is to develop a magnetic model which will calculate the appropriate correction to be applied to the data.

This task Includes: (1) identifying factors which cause compensator leveling instruments to deviate from the calibrations performed in the laboratory; (2) estimating the corrections Independent of the calibrations, e.g., through profiles and adjustment; (3) estimating factors for Instruments which cannot be calibrated; and (4) developing and implementing a procedure to check and apply the correction.

The VNB has Identified all leveling lines which were observed using compensator leveling Instruments. Magnetic corrections, computed from calibration data, have been applied to a few leveling lines. Profiles were prepared comparing both corrected and uncorrected values to previous leveling data. It appears that the correction Is overcorrecting some of the lines. NGS' Geodetic Research and Development Laboratory

(GRDL) is currently studying magnetic error. The study should be completed in time to finish the REDUC4 processing by March 1985.

Appropriate A Priori Estimates of Standard Errors. When different types of data are combined and adjusted. It Is essential to Impose a correct relative weighting scheme. This means that a priori standard errors of observations must be estimated for each group of data. This task Includes Identifying the different groups of leveling observations, and establishing and Implementing a procedure to determine the appropriate a priori standard error of observations in each group.

Groups of data (according to Instrumentation, field procedures, etc.) have been Identified but may be modified after additional analysis. Different methods for estimating variance components in least-square adjustments are being considered. The Iterative Almost Unbiased Estimation (IAUE) technique (Lucas, 1984) has been Implemented on NGS' HP1000 minicomputer. Other analysis Include: (1) comparing old and new section and loop statistics, (2) profiles, and (3) formal error studies of past field techniques.

Water-Level Transfers and Tidal Information. This task includes defining the data formats for water-level transfer and tidal data, loading the data, and estimating their observational accuracies.

The 1977-63 water-level transfers and current primary National Tidal Observation Network tidal data (monthly means) have been keyed and placed in computer-readable form by the Tides and Water Level Branch, Office of Oceanography and Marine Services. The data heed to be reformatted and placed In the Vertical Network Data Base. Studies have been performed which estimated the accuracies of these data (Stoughton, 1980). Additional analysis will be needed to determine how they should be weighted in the NAVD final adjustment.

Interpolate"Gravity Values for Bench Marks. The NAVO readjustment will be performed using geopotential numbers. This requires estimating gravity values for all bench marks Involved in the readjustment. Phase 1 of this task consists of Interpolating gravity values and their corresponding estimates of accuracy for all bench marks in the Vertical Synoptic file. The last of the gravity values will be loaded by April 1985.

The second phase of this task is to perform a study to determine If all gravity values are accurate enough for NAVD 88 purposes. A procedure will be developed which examines elevation differences, and determines If the gravity value estimates are accurate enough. If additional gravity values are required, then an observation plan for an area win be developed and Implemented. It 1s not anticipated that many areas of the country win need additional observations.

Development of NAVD Software. The Vertical Network Branch has identified that 3 staff-years of software development effort is required 1n support of the NAVD 88 project. The programs are needed to increase productivity without sacrificing quality. They mostly include graphics routines; some management tools have also been identified.

Some examples of the programs include plotting profiles, junction details, loops, residuals, and networks. Having graphics capabilities is extremely Important to the timely success of the project. The specifications and algorithms for each program need to be documented.
Then they win need to be coded, debugged, and implemented.

In addition to the programs mentioned previously, the programs to perform the Helmert blocking process need to be designed, coded, debugged, and Implemented. VNB is currently studying all programs Involved with the NAD 83 Helmert blocking system. A majority of the programs can be utilized as they exist today. However, programs that create or modify lowest-level Helmert blocks will have to be rewritten because they are specific to horizontal data. A detailed analysis of these programs needs to be performed and the Impact should be considered In any future purchase of a VNB minicomputer.

<u>NAVD 88 Crustal Movement Studies_and Procedures.</u> This task includes identifying areas of the network which are Influenced by crustal motion, and establishing and implementing a procedure to account for these movements.

During the past few years, VNB has been analyzing different numerical techniques in an attempt to model crustal movement. This would enable the NAVO 88 project to include most data and bench marks In one adjustment. The studies, performed mainly In the Houston-Galveston, Texas, area have been successful In Identifying the data required to model movements precisely. The lack of required geologic and hydrologic Information, along with Inadequate network design, makes modeling many areas for precise movements very questionable.

Areas of the networks most likely Influenced by crustal movement are fairly obvious, e.g., California, Texas Coast, sections along the East coast, and sections of the U.S. Northern border. .Other areas will be identified as block validation continues and additional research material Is obtained. It may be possible to modify some observations for crustal motion effects, but It Is more likely that most areas will be constrained to the framework network surrounding the area in question. A plan defining the technique to be implemented in these "moving" areas will be developed and documented.

A plan defining the technique to be implemented in California has been developed and documented. The plan includes defining a primary network In California which is consistent within itself, and then making modifications to accommodate crustal motion.

<u>Framework Adjustments.</u> This task will Include designing and analyzing framework networks (regional and national). The analysis will be helpful In determining the effects of various datum constraints, magnitudes of height changes from the NGVD 29 datum. Influences of systematic errors, deficiencies 1n network design, and additional releveling requirements.

A plan of action will be developed and documented. Studies comparing local mean sea level to geodetic leveling along the East and West coasts are currently being performed

(Zilkoski, 1984). In the past, a major analysis was performed in the Gulf Coast region from Texas to Florida. The entire set of leveling observations will be processed through program REDUC4 by March 1985. At that time, all areas of the country can be analyzed for network deficiencies and the releveling schedule can be made more optimum.

Data Base Design. Entry, and Retrieval. This task Includes defining data elements and developing routines to load, edit, and retrieve data from the NGS Integrated data base (IDS). The VNB and Systems Development Branch are working together on a systems analysis study of all VNB activities. This will help In Identifying all data elements needed for IOB. Once IDB 1s operational, routines win need to be developed to load, edit. and retrieve data from IDB.

GPS and NAVD 88. GPS-derlved heights cannot be used, as is, as observations in the NAVD readjustment project, however height differences and geoid undulation differences should be helpful in detecting and providing an upper limit on systematic errors in leveling data and for strengthening the network.

The VNB Is working with NGS' Astronomy and Space Geodesy Section, on a study to estimate geoid slopes using GPS and differential leveling (Hothem, Fury, and Zilkoski; 1984). This Is a start, but a comprehensive plan of action must be developed to look at what GPS offers the NAVD 88 project.

Studies have been performed estimating orthometric heights using GPS and gravity (Engelis, Rapp, and Bock; 1984) and estimating subsidence using GPS-derlved heights (Strange, 1984). GRDL Is currently looking Into what GPS offers the NAVD 88 project.

Datum Definition. Datum definition is one of the last tasks which will be performed in the NAVD 88 project. There are many factors which need to be considered before a decision can be made. It may be as simple as fixing the height of a tidal bench-mark and performing a block shift to minimize differences between NAVD 88 heights and the latest Local Mean Sea Level epoch heights. However, there are still some unanswered questions: How do we Incorporate and weight tidal heights and waterlevel transfers? Can we estimate the effects of sea surface topography (SST) at tidal stations? Can satellite Information help control datum distortions?

These tasks are currently being looked at; we are developing and documenting a specific plan of action.

Helmert Blocking. This task consists of partitioning 1.5 million unknowns and associated observations into manageable blocks and solving a least-squares adjustment of the entire data set.

The blocking strategy of NAVD win be easier to define than for other large adjustments such as the North American Datum (NAD) readjustment (McKay and Vogel, 1984). After the first-level blocks. It Is anticipated that 90 percent of the unknowns will be "Interior". A blocking strategy needs to be developed which includes boundaries and the unknowns that are to be carried to the higher levels. The Helmert blocking technique for adjustment of data has been documented by others (Dillinger, 1978; Isner. 1978; Wolf, 1978).

Exchange of Data with Canada,, Mexico, and Central America. This task Includes Identifying Junction stations and associated Information, along with their formats, which win be required at the countries' borders for the final solution. The corrections and methods of applying corrections win also be addressed. There is time before the junction stations are actually needed, but meetings should be held to establish preliminary formats and to determine the procedures which win be used to apply the corrections, as well as which corrections are going to be applied.

Publication. This task Includes reviewing descriptions on a random basis, and publishing final adjustment heights In 30 minute quads. However, It Is planned to have NAVD 88 adjusted heights available to the public immediately following the adjustment. They will be loaded Into NGS' IDB and the public win be able to access the IDB directly.
It Is hoped that most people will access the NGS IDB when requesting data. With the price of computers decreasing and their sophistication increasing, this Is not an unrealistic goal. In any event, they will also be available In hard copy and microform, at a higher cost.

Progress and Final Reports. Detailed progress reports addressing each task and their status are prepared every 6 months.

The final report is not scheduled for completion until September 1989. This report win give the history of the network and readjustment project; technical decisions made about weights Imposed, observations used, adjustment technique, and crustal motion Information. Previously published reports win be the main source for the final report.

CONCLUSIONS

It Is obvious that the NAVD 88 project requires an enormous amount of effort. The project, scheduled for completion In 1988, has dominated Vertical Network Branch activities since the project received approval and funding, beginning in FY 1978. The production and research efforts are on schedule.

The benefits of NAVD 88 make this effort worthwhile. A vertical control network containing a consistent, accurate set of adjusted heights has been needed for a long time. Other products and services resulting from the project win be used by people for a long time to come. For example, the observed elevation differences which are now In computer-readable form, are available for future crustal motion studies and regional readjustments. The real benefits win become apparent when the multitude of users start using the results of the new adjustment.

REFERENCES

Batazs. Emery I., 1984. "Preliminary Vertical Data Reduction Procedures," ACSM Bulletin. December 1984, pp. 25-26.

Berry, Ralph M., 1976. "History of Geodetic Leveling In the United States". Surveying and Mapping. 36(2). pp. 137-153.

Dininger. William H., 1978. "Helmert Block Higher Level System," Proceedings of the Second International Symposium on Problems Related to the Redefinition of North American Geodetic Networks. Arlington. Virginia. April 24-28. 1978.

Engelis, R. H. Rapp, and Y. Bock, "Measuring Orthometric Height

Differences with GPS and Gravity Data," presented at the Chapman Conference on Vertical Crustal Motion: Measurement and Modeling. Harpers Ferry, West Virginia, October 22-26, 1984.

Federal Register, 1976. 41 (96). p. 20202.

Federal Register, 1983. 48 (214). p. 50784.

Hothem, Larry D., R. J. Fury, and D. B. Zilkoski, "Determination of Geold Slopes using GPS," presented at the Chapman Conference on Vertical Crustal Motion: Measurement and Modeling. Harpers Ferry, West Virginia, October 22-26, 1984.

Isner, John F., 1978. "Helmert Block Initial Level System," Proceedings of the Second International Symposium on Problems Related to the Redefinition of North American Geodetic Networks. Arlington, Virginia, April 24-28, 1978.

Koepsell Katherlne S. and R. Bruce Ward. 1984. "NGS Input Formats and Specifications for Vertical Control Data," ACSH Bulletin. October 1984, pp. 35-36.

Lucas, James R., 1984. "A Variance Component Estimation Method for Sparse Matrix Applications," Bulletin Geodeslqua (In press).

McKay, Edward J. and Steven A. Vogel, 1984. "The North American Datum of 1983: Necessity, Status, and Impact," presented at the ACSM/ASP Convention. San Antonio, Texas, September 9-14, 1984.

National Academy of Science, 1978. Geodesy, Trends and Prospects, Committee on Geodesy, National Research Council.

National Ocean Survey, 1976. Releveling of the Vertical Network. Issue paper, 68 p.

National Ocean Survey. 1982. Geodetic Surveys and Services Program Plan 1980-1990, Washington. D.C., 26 p.

Office of Management and Budget. 1973. Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying, Executive Office of the President.

Rumpf W. E. and H. Meurlsh. 1981. "Systematische aunderungen der

zlelllnie eines prazlslons kompensator-nlveTllers—lnsbesondere des Zeiss N1 1 —durch magnetlsche glelch - und wechselfolder. XVI International FIG Congress, Montreusx, Switzerland.

Stoughton, Herbert W., 1980, "Investigation of the Accuracy of Water Level Transfer to Determine Geodetic Elevations In Lake Ontario," dissertation for a Doctor of Philosophy (Civil Engineering); University of Michigan; (published by University Microfilms International; Ann Arbor, Michigan)

Strange, William E., "Accuracy of GPS for Monitoring Vertical Motions," presented at the Chapman Conference on Vertical Crustal Motion-Measurement and Modeling. Harpers Ferry, West Virginia, October 22-26, 1984.

Tin, John H., 1983. "The Processing of Archival (Historic) Leveling Data, "ACSM Bulletin. February 1983. pp. 27-28.

Whalen, Charles T.. "Precise Trigoncxnetic Leveling," presented at the Chapman Conference on Vertical Crustal Motion: Measurement and Modeling. Harpers Ferry, West Virginia. October 22-26, 1984a.

Whalen, Charles T.« "Magnetic Field Effects on Leveling Instruments," presented at the Chapman Conference on Vertical Crustal Motion; Measurement and Modeling. Harpers Ferry. West Virginia. October 22-26. 1984t>.

Wolf, Helmut. 1978. "The Helmert Block Method - Its Origin and Development." Proceedings of the Second International Symposium on Problems Related to the Redefinition of North American Geodetic Networks. Arlington, Virginia. April 24-28, 1978.

Zllkoskl. David B., "Geodetic Leveling and Mean Sea Level Along the

East Coast of the United States," presented at the Chapman Conference on Vertical Crustal Motion: Measurement and Modeling. Harpers Ferry, West Virginia. October 22-26, 1984.